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PRESSURE MEASUREMENTS IN EXPLOSIVELY STRESSED LIQUIDS.(U)
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 14 ARCSL-TR-79076	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 PRESSURE MEASUREMENTS IN EXPLOSIVELY STRESSED LIQUIDS		5. TYPE OF REPORT & PERIOD COVERED 9 Technical Report, Oct[redacted]976-Sep[redacted]79
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 Raymond P. Tytus		8. CONTRACT OR GRANT NUMBER(s) 16
9. PERFORMING ORGANIZATION NAME AND ADDRESS Commander/Director, Chemical Systems Laboratory ATTN: DRDAR-CLB-P Aberdeen Proving Ground, Maryland 21010		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project 1L161102A71A Scientific Area 4
11. CONTROLLING OFFICE NAME AND ADDRESS Commander/Director, Chemical Systems Laboratory ATTN: DRDAR-CLJ-R Aberdeen Proving Ground, Maryland 21010		12. REPORT DATE 11 Jan[redacted]80
		13. NUMBER OF PAGES 19
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) 12 18		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE NA
16. DISTRIBUTION STATEMENT (of this Report) 1) SEE Approved for public release; distribution unlimited. 19) AD-E410		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Explosive projector; Peak pressure; Pressure transducer; Viscoelastic liquid; Phase change; Liquid dissemination		

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this study was to acquire and exploit techniques for measuring pressure-time histories in liquid-filled containers subjected to explosively generated stresses. Under this study, a representative liquid (water) and seven other liquids, including two viscoelastic liquids, were tested using an explosive liquid projector. Pressure histories were compared as a function of explosive weight and degree of liquid confinement. Differences in their dynamic response were noted. A peak pressure predictive equation was established for explosively stressed

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20. ABSTRACT (Contd)

liquids in an explosive projector. For the explosive projector dissemination trials, a peak pressure of 217 kpsi (15 kb) is predicted using this equation. Possible phase transitions are indicated for two of the liquids tested, tetrachloroethylene and diethylmalonate, when stressed to a pressure of 63 kpsi (4.3 kb).

PREFACE

The work described in this report was authorized under Project 1L161102A71A Scientific Area 4, Chemical Munitions. This work was performed between October 1976 and September 1979. The experimental data are recorded in notebooks TSD 9180, 10006.

Acknowledgments

The author wishes to thank Mr. Bernard V. Gerber, Chief of the Physics Branch and Mr. Arthur K. Stuempfle, Chief of the Operational Sciences Section, whose earlier work with the explosive projector formed the basis for this study. Thanks are also rendered to Mr. Craig R. Allan, Operational Sciences Section, Physics Branch, Research Division, who provided a technical critique of the study in many discussion sessions and Mr. Leonard Edwards of the Operational Sciences Section, Physics Branch, Research Division, who assisted and contributed much to this study.

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PRESSURE MEASUREMENTS IN EXPLOSIVELY STRESSED LIQUIDS

I. INTRODUCTION.

The use of explosives for the dissemination of chemical agents is a common technique employed in many munition systems. The rapid, high-energy release of explosives permits effective area coverage by the agent in a very short time. However, because of this high-energy release detrimental effects on the agent are also possible.

Recent explosive projector studies were conducted to compare the performance of explosively disseminated volatile liquids and to determine these distributions of liquid mass in space within milliseconds following detonation.[1] The technique was based on determining the height above an explosive projector at which 50% of the initial mass was in liquid aerosol form (drops > 15-μm diameter) and 50% of the liquid mass was found below this height as measured by a three-dimensional-sampling matrix. This median height was termed the Z 50 value for the liquid. A correlative relationship was established by Monsanto Research Corporation in an attempt to relate the behavior to the physical properties of the liquid. Monsanto also developed a computer technique to calculate a Wiebull distribution mean value of Z 50 using the experimental data. Explosive-projector Z 50 test distances indicated dramatic deviations among the liquids tested. It was hypothesized that these differences may be due to transient changes in the physical properties of liquids caused by the explosively induced shock waves. It was quite possible that significant differences between static and dynamic parameter values were being realized.

The purpose of this study was to acquire and exploit techniques for measuring pressure-time histories in liquid-filled containers subjected to explosively generated stresses. The approach was to establish an operational high-pressure transducer system for measuring shock pressures in liquids by evaluating different pressure measurement techniques using a representative liquid in order to obtain maximum signal response with a minimum of background interference. Once established, this technique was used to determine the effect of explosive size and degree of liquid confinement on pressure-time histories of the representative liquid. Finally, similar pressure-time histories for liquids of interest were acquired for comparison and for possible identification of differences in their dynamic response to explosive stresses.

II. EXPERIMENTAL PROCEDURE.

A. Experimental Setup.

The initial phase of the test program was devoted to establishing an operational pressure-transducer-measurement capability which had a minimum of background noise. Results from this effort indicated that high-voltage (HV) firing of the explosive introduced significant electrical noise to the output pressure trace and that in some cases the trace was completely masked (originally the use of the HV-firing circuitry was considered mandatory because high-speed-camera studies were planned which required this high-synchronization capability. However, these studies were eventually dropped). A 6-volt battery successfully fired the explosive

[1] Gerber, V. V., and Stuempfle, A. K. A New Experimental Technique for Studying the Explosive Comminution of Liquids. 1976 Army Science Conference Proceedings. June 1976.

and did not introduce any significant electrical noise to the pressure signal. Generally a 6-volt battery may not be used as a trigger source because of the large time jitter normally present. It can be used in this study, however, because of a unique synchronization feature possessed by the recording instrument that will be discussed later.

Figure 1 shows the basic pressure transducer system used in the study. Included are (1) an explosive liquid projector and related hardware, (2) pressure transducers and associated amplifiers and cables and (3) a recording oscilloscope. Figure 2 shows a typical pressure-time-trace polaroid picture obtained using a 6-volt battery to fire the explosive.

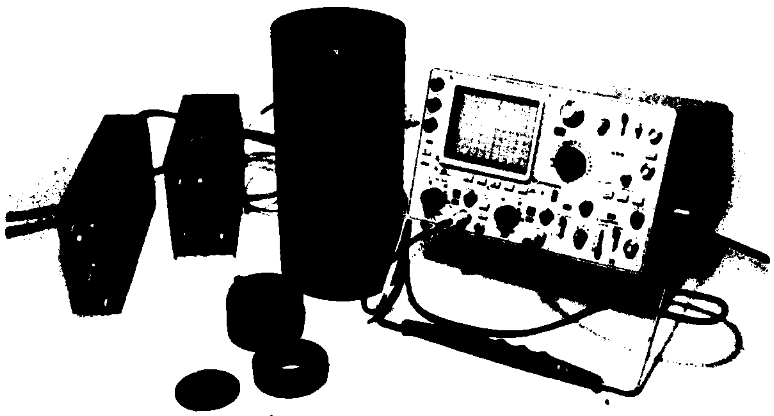

Figure 1. Basic Pressure Transducer System

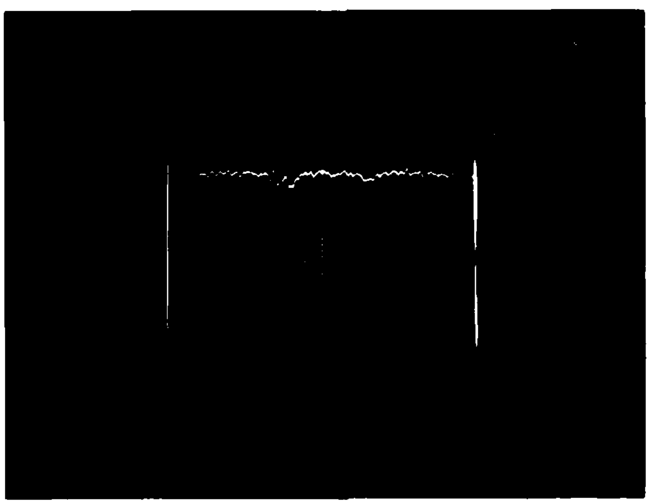

Figure 2. Typical Pressure-Time Trace
(Sweep 20 μsec/div; Pressure 20 kpsi/div)

1. <u>Explosive Projector.</u>

Figure 3 shows a cross-sectional view of the explosive projector unit. The projector is a steel cylinder 6 inches in diameter by 12 inches in length with a nearly 1-inch bore in the center. The explosive is positioned at the end of the 1-inch bore with the detonator wires exiting through a hole provided at the bottom. The air volume is nominally 4.1 in^3 for this configuration corresponding to a depth of 5-1/8 inches (smaller air volumes can be obtained by inserting steel slugs at the bottom of the internal 1-inch inside diameter prior to insertion of the explosive). A 0.035-in acrylic disc positioned within the 1-inch bore contains the 2.38 in^3 of liquid under test. Two pressure transducer taps are provided (only the top one is shown on the figure for clarity). One tap is positioned 5/8 in from the top of the liquid cavity, the second is radially displaced from the first separated by a 1/2-in longitudinal distance. When a rupture disc is used, it is positioned over the liquid column and secured with a threaded cylindrical cap (not shown on figure).

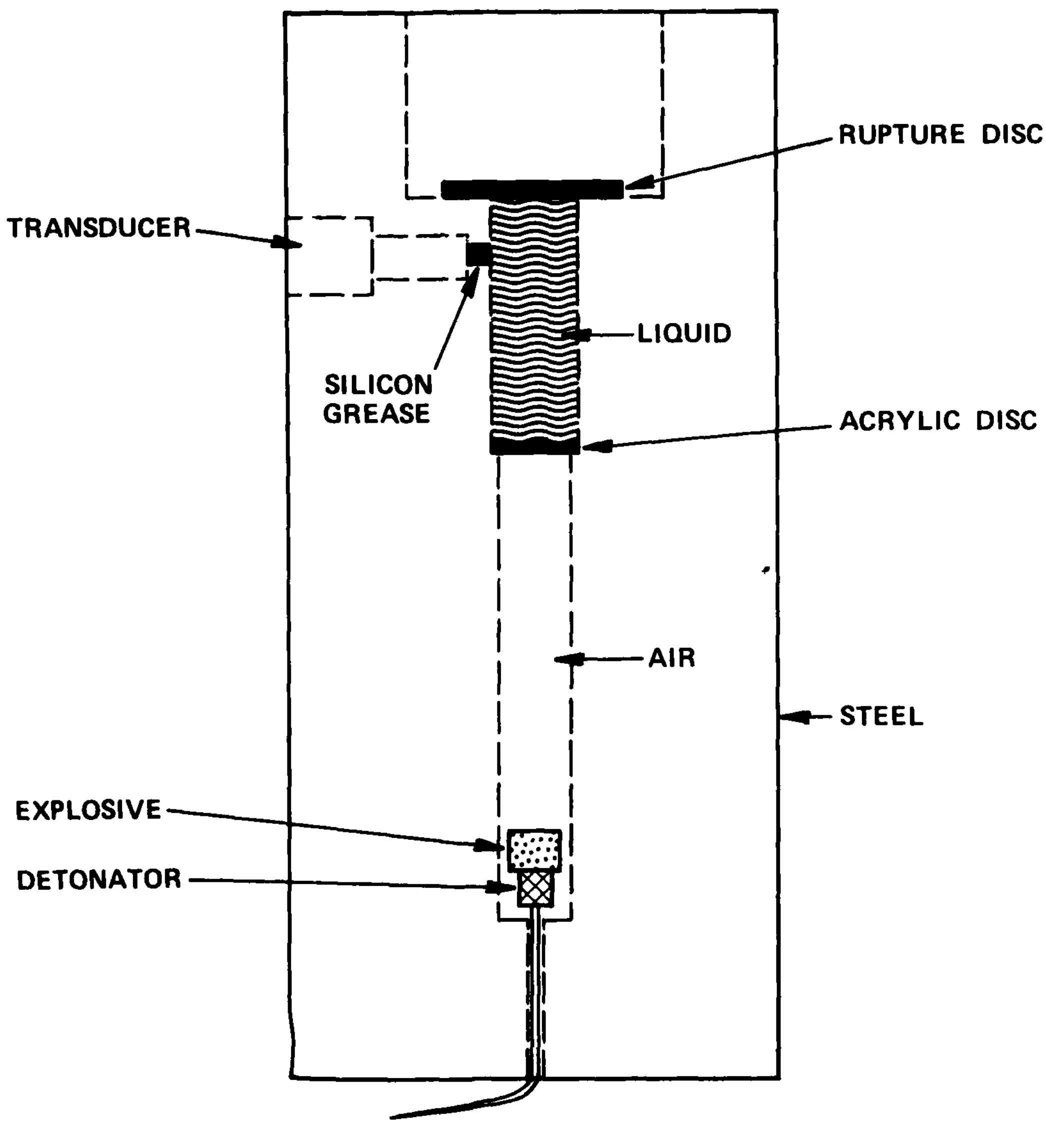

Figure 3. Cross-Sectional View of Explosive Projector

2. Pressure Transducers.

The pressure transducers selected for the study were manufactured by PCB Piezotronics, Incorporated. They are high-pressure quartz transducers, model number 109A02, designed for shock wave and ballistic applications. The overall length of the transducer is 1.68 inches with an active surface diameter of 0.248 inch. Rated maximum pressure for the transducer is 120,000 psi. For improved signal quality, a compensating accelerometer was used in the transduced body to reduce vibration sensitivity and minimize resonance effects of the high-frequency (500 kHz) tranducers. As part of the transducer system, dual-charge amplifiers (see figure 1) are used to convert the signals from the transducers to standard signals compatible with recording instrumentation. Calibration curves were supplied for the transducers by the manufacturer.

3. Recording Oscilloscope.

The output pressure-time histories were recorded using a Tektronix model 485 wide-bandwidth portable oscilloscope and a high-writing-speed Polaroid camera, Tektronix model C-31. Excellent signal trace quality at the fast sweep rates required (10-50 microseconds) made the oscilloscope ideally suited for this application. Also, accurate internal trigger-control levels permitted sweep synchronization with the pressure signal using the signal itself as the trigger source. This capability permitted the use of a 6-volt battery to fire the explosive and to eliminate the undesirable HV signal pickup seen in the earlier pressure traces recorded in the study.

B. Experimental Technique.

The explosive used in this study was pressed tetryl pellet to minimize explosive-handling requirements. Cylindrical tetryl charges 1/4-in X 1/4-in, 3/8-in X 3/8-in, and 1/2-in X 1/2-in were used corresponding to masses of 0.3, 1.03 and 2.46 grams respectively. An NND 211 detonator cap was used to initiate the tetryl.

In daily operation, the explosive train, detonator and tetryl, was first assembled and placed in the projector body (if a steel slug was used to reduce the air volume of the explosive cavity it was placed in position before the explosive). The detonator was then connected to the firing line, the other end being shorted and tied to ground. The 0.035-inch acrylic disc was placed in position, glued in place and allowed to dry. Silicon grease was put in the transducer cavity to eliminate air gaps between the test liquid and transducer. During this period, the transducer amplifier and recording oscilloscope were turned on to allow the electronic circuits to stabilize. The transducer was placed in the explosive projector body, tightened, and the signal output cable connected. The test liquid was placed in the liquid cavity and the temperature recorded. The test chamber was then locked. The recording-instrumentation circuitry was established and after the standard explosion-warning signal was given, the explosive was detonated using a 6-volt battery system. The oscilloscope pressure-time trace was recorded on Polaroid film.

C. Liquids Tested.

The reference liquid used to obtain baseline data was water. The other liquids included two which were used in the referenced-explosive-projector study as well as some viscoelastic liquids of current interest. The following liquids were those used in the study (excluding water): ethylene glycol, polyethylene glycol-200 (PEG-200), polyethylene glycol-200 with addition of 0.25% by weight Klucel M,[2] bromotoluene, tetrachloroethylene, diethylmalonate, and bis(2-ethylhexyl) hydrogen phosphite (Bis) with 2.5% polyisobutylmethacrylate[3] (PIBM).

III. TEST RESULTS.

Figure 4 shows the average of the pressure peaks measured for the reference liquid (water) plotted versus explosive weight at the three explosive air cavities used. Based on test results obtained for the 4.66-in^3 air cavity configuration, a pressure peak predictive equation was derived as a function of explosive weight and explosive air cavity volume. The equation is:

$$Pp = (18.64 + 76.15\ W_T)\ \frac{1}{V_{AC}}$$

where Pp is pressure peak in kilopounds per square inch (kpsi), W_T is the explosive mass in grams and V_{AC} is the volume of the explosive air cavity in cubic inches. The solid lines on figure 3 were drawn according to this equation with the appropriate parameters used. Good agreement with the experimental data is indicated. The zero-explosive-weight pressures shown correspond to detonator cap explosive pressures.

Figure 5 shows the average pressure-peak results obtained for the other liquids tested. Three graphs are shown for clarity, each corresponding to one of the explosive cavities used in the test series. Once again, good agreement is indicated except for two liquids, tetrachloroethylene and diethylmalonate, using an explosive weight of 2.46 grams and an air cavity of 3.44 cubic inches. (Ethylene glycol, PEG-200 and PEG-200 with Klucel indicate higher pressure but these tests were made early in the test program before the explosive air cavity had increased in volume from 4.1 in^3 to 4.66 in^3 caused by cratering of the side walls near the explosive. The first two water tests made at the same time as those above gave peak pressures of 74 and 72 kpsi compared to baseline tests made later in the program of 60, 64, and 60 kpsi.)

IV. DISCUSSION.

The explosive projector was designed to simulate a section of an in-flight liquid-filled projectile containing an explosive central burster. During flight, centrifugal forces created by the high spin of the projectile force the liquid to the inner wall of the projectile thus forming a liquid cylinder. The air void remaining fills the volume between the explosive central burster and liquid cylinder. The final projectile radial configuration of explosive, air cavity, liquid and casing wall is the same as that in the explosive projector unit. (The rupture disc was eliminated in this study when dissemination trials indicated no difference in results with and without the disc.)

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[2] Manufactured by Hercules, Incorporated.

[3] Obtained from F. Dagostin, Development and Engineering Directorate, Lot No. 94-5095 SW-63/0082.

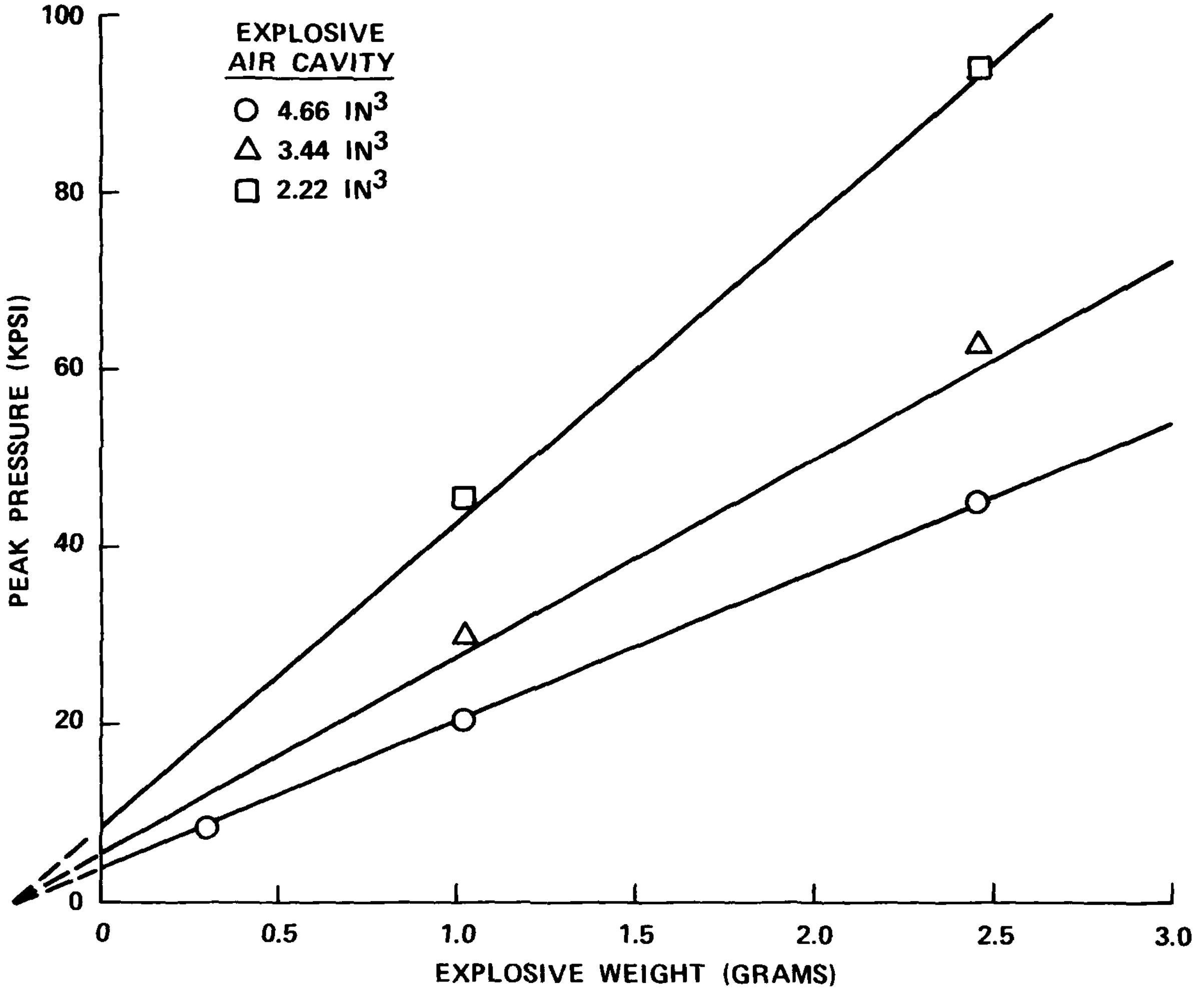

Figure 4. Reference Liquid (Water) Peak Pressure Versus Explosive Weight

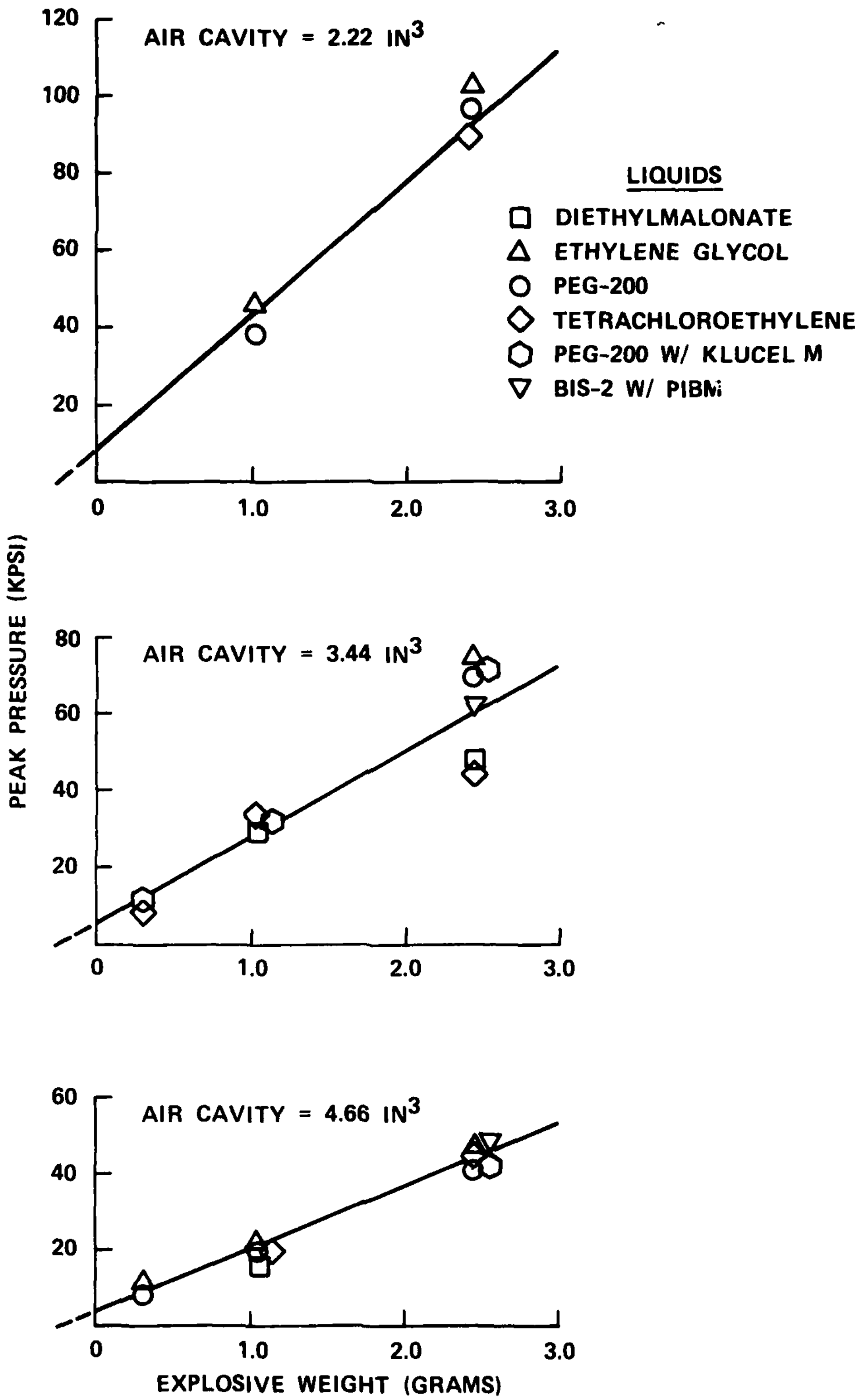

Figure 5. Test Liquid Peak Pressure Versus Explosive Weight

The pressure predictive equation found in this study can be used to estimate the pressures developed in the earlier explosive-projector-dissemination studies. The explosive used in that study was composition C-4 packed to a density of 1.4 gm/cm^3. The detonation pressure at this density is estimated to be 205 kilobars (kb) compared to the estimated 200 kb for the tetryl pellets (density = 1.7 gm/cm^3). Assuming the two explosives will behave similarly, based on approximately equal detonation pressure, and using an explosive weight of 7.4 grams and an air cavity of 2.68 in^3 (that used in the referenced study), the predictive pressure is 217.2 kpsi or 15 kb (hemispherical glass capsules were used in the dissemination trials to contain the liquid but results from the present study indicated no adverse effect in the pressure trace except to increase the pressure slightly as a result of the air cavity volume decrease, as predicted by the equation).

The two liquids which exhibited pressure peaks different than those predicted were diethylmalonate and tetrachloroethylene. This difference only occurred at the one explosive weight-air cavity configuration, all other pressures were as predicted. This type of behavior indicated that a possible phase transition could have occurred in the liquid.

Work performed by Stanford Research Institute[4] has shown that phase transitions can occur in liquids which exhibit a cusp in their pressure-volume relationship (also called the "Hugoniot"). If on the Hugoniot curve a cusp intersects the straight line drawn from the base of the Hugoniot to the applied shock pressure (i.e., the Rayleigh line), the applied shock will split into two waves. The waves will travel at different velocities and will therefore separate in time. The results obtained for diethylmalonate and tetrachloroethylene showed only one apparent pulse but the recorded pressure pulse exhibited a somewhat flattened top compared to the normal peaked response of the other liquids. It is possible that the pressure pulse widths and velocity differences between the two waves produced a response equal to the sum of the waves such that the rise of the second wave corresponded to the fall of the first wave. In this case the sum would be a constant amplitude i.e. flat top, if the waves were approximately equal. Additional and more comprehensive analyses of this event should be pursued.

V. CONCLUSIONS.

The following results were obtained:

1. A peak pressure predictive equation was established for explosively stressed liquids in an explosive projector.

2. For the explosive projector dissemination trials, a peak pressure of 217 kpsi (15 kb) is predicted using this equation.

3. Possible phase transitions are indicated for two of the liquids tested, tetrachloroethylene and diethylmalonate, when stressed to a pressure of 63 kpsi (4.3 kb).

[4] Erlich, C. C., and Crewdson, R. C. SRI International. Final Report. Contract DAAA15-69-C-0598. Effect of Dynamic Properties Upon Liquid Dissemination. April 1970.

VI. RECOMMENDATIONS.

It is recommended that the liquids which exhibited possible phase transitions be investigated further to determine the nature and extent of the phase transition and its influence on the dissemination behavior of the liquids.

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